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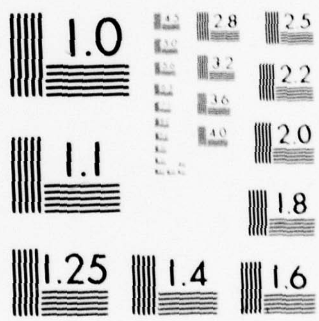

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ANALYSIS OF AVAILABLE LIFE CYCLE COST MODELS AND THEIR APPLICATIONS

JUNE 1976

JOINT AFSC/AFLC COMMANDER'S WORKING GROUP
ON LIFE CYCLE COST
ASD/ACL
WPAFB, OHIO 45433

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CAPTAIN DWIGHT E. COLLINS

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JOINT AFSC/AFLC COMMANDERS' WORKING GROUP
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FOREWORD

Some have suggested that one or a small number of ideal life cycle cost (LCC) models developed by a select group of specialists would provide the analysis methods needed to address most or all Air Force life cycle cost problems. However, quite the reverse is true. This report summarizes the findings of the Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost in reviewing currently available LCC models. It is an update of an earlier Working Group report entitled "Analysis of Available Life Cycle Cost Models and Actions Required to Increase Future Model Applications". It includes discussion of several models developed since the publication of the earlier report.

The Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost is attempting to continually keep abreast of new life cycle cost models and methods in order to facilitate the increased application of life cycle cost analysis throughout the Air Force. It is, therefore, requested that reports or other descriptions of new LCC analysis models and methods be forwarded to the Working Group Office for review and retention in the Life Cycle Cost Library. (ASD/ACL, Wright-Patterson AFB, Ohio 45433)

This report has been reviewed and approved.

John D S Gibson

JOHN D.S. GIBSON, Director
AFSC/AFLC LCC Working Group
Life Cycle Cost Office
Comptroller

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I. INTRODUCTION

Background

There has been considerable concern within the Department of Defense for some time about the high cost of defense systems and the rapidly increasing cost of supporting systems after they are placed into operation. The cost of operating and supporting defense systems over their useful life is generally greater than, and often several times greater than, the initial acquisition price. The Air Force life cycle costing (LCC) program is designed to bring about reduction in system and equipment operating and support costs, primarily through increased consideration and analysis of the operating and support implications of design alternatives. One important way to achieve these cost reductions is through more extensive and effective use of life cycle cost models. To achieve this goal, cost analysis and program personnel must first gain a greater awareness of the scope and adequacy of currently available models.

Nature and Use of LCC Models

The term, life cycle cost model, as used in this report, includes a diverse spectrum of mathematical models used to address some aspect of life cycle costing during the weapon system acquisition cycle. Four particularly important uses of LCC models that will be discussed are:

1. Computation of an operating and support (O&S) cost estimates which are used as a decision criterion by the Defense Systems Acquisition Review Council (DSARC) or other levels of management.

2. Computation of comparable O&S cost estimates for consideration during source selection.

3. Computation of O&S cost targets which are incorporated in contractual commitments, and success in meeting such targets.

4. Trading off alternative equipment design alternatives and support concepts on the basis of their impact on LCC.

Some of the ten different categories of models described in Chapter 4 and the appendix are much better suited for some of these uses than others. It is important that those wishing to use a model clearly understand both the use to which they will apply the LCC model, and the nature of the model being applied.

One important difference between LCC models should always be clearly understood. Some models, like the AFLC Logistics Support Cost (LSC) model, develop a cost based on the number of failures, or other support actions that occur and the cost required to respond to each. This type of model is sensitive to changes in design that affect failure rates. However, it assumes that support costs are accrued only when required. On the other hand, other models such as the CACE model use manning levels as inputs. These models are less sensitive to design differences, but do more accurately reflect the fact that personnel must be paid whether or not they are needed on any particular day. Both types of models have their strengths and weaknesses. Therefore, careful study is required to best match a specific type of model to a particular life cycle cost analysis issue or need.

Purpose and Scope of Study

The primary purpose of this literature review is to answer three questions with respect to the availability of models for life cycle cost analyses in the Air Force:

1. What types of models are available?

2. How and why do they differ?

3. To what extent are these models deficient in meeting life cycle cost analysis needs?

4. How can some of these deficiencies be overcome?

A secondary purpose of this review is to categorize existing life cycle cost models by use and characteristics, and to provide a brief description of one or more models in each category. This will give the reader greater insight into the nature of the various model categories and some knowledge of the experience to date in using specific models.

Those characteristics of a digital computer which most significantly affect costs are generally not the same characteristics that would affect costs of an airborne electronic countermeasures package. The same holds true for a flight simulator or a UHF radio. In short, almost every system/subsystem/component has certain unique characteristics (design, performance, etc) that influence its development, acquisition and operating and support costs. Because these characteristics vary widely and because of the different decision issues that occur throughout the life cycle of a system/subsystem/component, new life cycle cost models are being developed at a rapid rate. It was not practical to review all life cycle cost models either in existence or under development. Thus the approach

taken in this review was

1. To examine a set of representative life cycle cost models.

2. To provide answers to the four questions above based primarily on study of these models.

3. To present the representative model descriptions in a manner that (a) will make program managers aware of the capabilities of current life cycle cost analysis methods, and (b) will assist program personnel in selecting the life cycle cost models that are appropriate for analysis of the life cycle cost issues associated with their program.

Report Contents

Section II of this report is a brief summary of major study findings. Sections III and IV expand on these findings. Section III discusses the desired characteristics of LCC models. Section IV is divided into two parts. The first part establishes a set of categories for life cycle cost models. The second part discusses some recognized deficiencies associated with currently available models. The appendix discusses each of the ten model categories identified in more detail and describes those models in each category that were examined in the study. The set of models examined does not include all available models but is considered to be representative of currently available LCC modeling techniques. A bibliography of life cycle cost-related literature has also been provided.

II. SUMMARY OF FINDINGS

This review and analysis of available life cycle cost models yielded five major findings:

1. The use of life cycle cost models can provide valuable guidance for a wide range of program decision issues. There currently exist several examples where the use of a life cycle cost model has had an important impact on program decisions.

2. In order for a model to be useful for analysis of a specific decision issue, it generally must be oriented to a relatively narrow range of deicision issues and equipment types and its input data requirements must be relatively easy to fulfill. Therefore, general purpose life cycle cost models tend to be inadequate for specific applications because they (a) lack resolution with respect to specific decision issues, (b) do not reflect characteristics of peculiar equipment types, and (c) require data in formats that are too extensive or are not compatible with formats of available data.

3. Many more models are needed if life cycle cost is to have an impact on the total spectrum of decision issues and equipment types. In particular, there is a critcal need for models relating performance and design characteristics to operating and support costs. There are currently few models of this nature in existence. The development of such models can lead to reduced life cycle costs by providing a means for explicit consideration of operating and support costs during weapon system concept and design studies.

4. System and equipment specialists must become involved in structuring and using life cycle cost models in order to assure that models adequately reflect individual design and performance characteristics and are used in making important design decisions. Program personnel must also become involved in the use of models to assure that they adequately address the life cycle cost implications of decision issues associated with their programs.

5. Assistance must be provided to system and equipment specialists and program personnel if they are to increase their effective use of life cycle cost models in a timely manner.

III. DESIRED LCC MODEL CHARACTERISTICS

Experience of the AFSC/AFLC Life Cycle Cost Working Group has indicated that there are four primary characteristics desirable in LCC models, and that these characteristics must be present to some extent, if analysis using the model is to produce useful decision guidance. These characteristics are:

1. Completeness: The life cycle cost model must include all elements of life cycle cost appropriate to the decision issue under consideration. If a total life cycle cost estimate is needed for planning or budgetary purposes, the model must include essentially all elements of program cost. However, where the decision under consideration affects some but not all cost elements, only those costs affected need be considered in a life cycle cost model used to compare the relative costs associated with that decision issue. Where appropriate, the cost differences between alternatives should be considered for at least the following life cycle cost elements: RDT&E, acquisition, initial and replenishment spares, spare engines and modules, off-equipment repair, on-equipment repair, new item inventory management, support equipment, training equipment, data, new facilities, training activity, operating personnel, fuel, and disposal.

2. Sensitivity: To be useful for design trade studies and other decisions, life cycle cost models must be sensitive to the specific design or program parameters under study in order to resolve life cycle cost differences between the alternatives. While this should be obvious, it is a significant problem because most life cycle cost models are not sensitive to the many important design and performance parameters associated with Air Force systems and equipments. This problem is aggrevated by the fact that many different types of Air Force equipment have unique sets of design and performance characteristics.

3. Validity: If a life cycle cost model is to be used to compute the life cycle cost differences between design alternatives and these differences used as a basis for decisions, users must have confidence in the validity of the life cycle cost data computed with the model. The problem is that mathematical models are only crude abstractions and approximations of the real world. Therefore, some judgement will always be required with respect to how valid estimated cost differences are, and just how much weight should be given to estimated life cycle cost differences relative to other factors, in arriving at specific decisions.

4. Availability of Input Data: Accurate input data must be available

for a life cycle cost model to be useful. Some life cycle cost models are of questionable value because good estimates of important input factors cannot be obtained, or if obtained from vendors, cannot be validated by Government personnel as true and an equitable basis for comparisons among vendors. When a model is selected or when work is undertaken to develop a new model for a specific application, it is important that it be done with full recognition of any limitations there may be on the availability of valid input data.

Because it is not possible to incorporate 100% of all of these characteristics into a single model and because some model uses are more demanding with respect to one or more of these characteristics, many life cycle cost models have been developed. This then dictates the need that model users understand the nature, characteristics and weaknesses of different types of life cycle cost models, in order to best match specific LCC analysis needs to the spectrum of models available.

IV. ANALYSIS OF AVAILABLE LIFE CYCLE COST MODELS

Types of Available Models

This literature search revealed that there are numerous models available for addressing decision issues that affect life cycle cost. Some life cycle cost models have been developed to be used as general purpose analytical tools while others have been developed to meet specific program or analysis needs. Some models have been designed for application to a weapons system while others have been designed for specific types of subsystems/equipment (e.g., avionics). Some models have deterministic inputs while others have probabilistic inputs. Therefore, in order to gain better insight into the various attributes of different life cycle cost models, the Life Cycle Cost Working Group defined ten separate categories of models based primarily on the type of use for which each model was initially designed. These ten categories are:

1. Cost Factor Model - A model in which each cost element is estimated by multiplying a key weapon system parameter by a factor which is derived as a function of Air Force cost experience on similar weapon systems.

2. Accounting Model - A set of equations which are used to aggregate components of support costs, including costs of manpower and material, to a total or subtotal of life cycle costs.

3. Cost Estimating Relationship Model - A statistically derived set of equations each of which relates LCC or some portion thereof directly to parameters that describe the design, performance, operating, or logistics environment of a system.

4. Economic Analysis Model - A model characterized by consideration of the time value of money, specific program schedules and the question of investing money in the near future to reduce costs in the more distant future.

5. Logistic Support Cost Simulation Model - A model which uses computer simulation to determine the impact of an aircraft's flying program, basing concept, maintenance plan, and spare and support resource requirements on logistic support cost.

6. Reliability Improvement Cost Model - A set of equations that reflects the costs associated with various increments of improvement in equipment reliability.

7. Level of Repair Analysis Model - A model that, for a given piece

of equipment, determines a minimum cost maintenance policy from among a set of policy options that typically include discard at failure, repair at base, and repair at depot.

8. Maintenance Manpower Planning Model - A model that evaluates the cost impact of alternative maintenance manpower requirements or the effects of alternative equipment designs on maintenance manpower requirements.

9. Inventory Management Model - A model that determines, for a given system, a set of spare part stock levels that is optimal in that it minimizes system spares costs or minimizes the Not Operationally Ready Supply (NORS) rate of the system.

10. Warranty Model - A model that assesses the relative costs of having the Government do in-house maintenance versus having this maintenance performed by contractors under warranty.

A more detailed description of these ten categories is given in the appendix. Representative currently available models in each category and experience to date in implementing these models are also described.

Deficiencies of Available Models

This study indicated that there are four major deficiencies that are found in currently available life cycle cost models:

1. They are not sensitive to performance and design parameters.

2. They are too complex.

3. They require input data which frequently cannot be provided in a timely manner or with the desired level of confidence.

4. They are not sensitive to wear-induced failures.

These deficiencies are described in detail in the remainder of this section.

1. Model Sensitivity to Performance and Design Issues - The most well known type of life cycle cost model is the accounting model. Most accounting models compute operating and support (O&S) costs as a function of reliability and maintainability characteristics such as mean time between failure (MTBF) and maintenance manhours per operating hour. They do not relate O&S costs to system or equipment performance

and design parameters such as material type, dimensions, accuracy, speed, and range. This lack of model sensitivity to performance and design parameters is of particular concern since most conceptual planning and design trade studies evaluate alternative values for such parameters. Design sensitive life cycle cost models are also required for Validation and Full Scale Development phase design-to-cost trade studies.

2. Model Complexity - The use of many life cycle cost models and particularly those of a general purpose nature (i.e., applicable to more than one specific equipment or decision issue) is severely limited because of model complexity. Two types of complexity are common:

a. Some of the models involve large numbers of parameters. The reason for this is often the model builder's desire to be comprehensive in his treatment of costs. Unfortunately, the effect of this type of complexity is to obscure the typically small set of parameters that have a pivotal impact on life cycle cost. As a result, the model user may spend considerable time calculating estimates of parameters that have a very small impact on cost, when in fact, he should be spending this time getting better estimates of the more critical parameters. Clearly, complexity in the sense of large numbers of parameters implies extensive data requirements. The data issue will be discussed in a later paragraph.

b. Definition of parameters used in some models are unclear. This problem is found particularly in general purpose models. It is typically due to the fact that the model builder has had to minimize the descriptive content in his definitions in order to maintain the general purpose nature of the model. This lack of clear definitions is one reason why general purpose life cycle cost models are not used more frequently.

3. Input Data Requirements that are Difficult to Fulfill - The inability to gather required input data for life cycle cost models is frequently the reason why these models don't get used. Two types of data problems are common:

a. Models require extensive input data. In order for the model user to have confidence in the results of model computations, he must be able to ensure that model input data is valid. This often calls for careful scrutiny of each input data value. As the number of pieces of required input data for the model increases, the task of validating the data may become very time consuming. In many cases, this time may not be available, e.g., when several contractors submit several thousand elements of model input data as part of a bid proposal and Government analysts have a

very limited amount of time in which to validate this data, due to source selection schedule constraints. In such cases, model results cannot be relied on and, as a result, have very little impact on decisions. The tendency toward large input data requirements is due again to the model builder's desire for an all-inclusive cost structure so that his model might be applicable to many decision issues and many equipment types.

b. Required input data are not compatible with available historical data. Currently, it is generally recognized that the most feasible approach to forecasting field operating and support costs of new Air Force equipment is to estimate these costs based on field experience of similar equipment in the inventory. However, the process of extrapolating historical data to new equipment is generally not easy and certainly not precise. One problem frequently encountered here is inconsistencies in definitions between available historical data elements and corresponding input data elements called for by currently available life cycle cost models. Other extrapolation problems exist. For example, maintenance data is generally collected by Work Unit Code (WUC). However, there is no standardization of assigned WUC below the subsystem (two-digit) level. In addition, component repair costs at the depot level are not identified by aircraft if the component is common to more than one aircraft.

4. Lack of Sensitivity to Long Term Wear-Induced Failures - Most life cycle cost models that compute support costs use a parameter such as MTBF to describe reliability. The MTBF is typically used to calculate the number of failures per year which, in turn, is used to compute repair cost per year. This annual repair cost is then converted into total repair cost by multiplying by the expected number of years of operation. These computations essentially assume that failures occur at random and that the number of failures is proportional to the number of hours of total force operation.

While this assumption is valid for some devices such as electronics, it is not for devices that are subject to long term wear-induced failures. If the wear-induced failure can be predicted, the cost associated with the failure can be estimated. In cases of this nature, preventive maintenance is generally used to avert the failure. Depot overhaul of engines is an example of this type of maintenance. However, in cases where the frequency of wear-induced failures cannot easily be predicted, e.g., the occurrence of failures due to aircraft structural fatigue, the costs related to these failures are typically ignored by existing life cycle cost models. Hence, in cases where depot overhaul due to airframe fatigue problems may be significant, most existing life cycle cost estimating models will produce an unrealistically low estimate. Moreover, since the models ignore wear-related failures, they cannot be used to determine the

impact of alternative designs on costs resulting from such failures. Clearly, the problem of developing relationships that reflect long term wear-related support costs as a function of performance and design parameters is significant and deserves more attention.

APPENDIX

DESCRIPTION OF REPRESENTATIVE AVAILABLE LIFE CYCLE COST MODELS

1. COST FACTOR MODELS

1.1 General Background

The Air Force has used cost factor models both to develop aircraft and missile squadron annual operating cost estimates for use in life cycle cost (LCC) comparisons and for planning, programming, and budgeting exercises. In particular, this type of model has been used to compute several recent weapon system O&S cost estimates for submission to the Defense Systems Acquisition Review Council (DSARC) and for use during several recent Program Assessment Reviews (PARs).

The cost factor model typically estimates O&S costs at the weapon system level by identifying such cost elements as spares, support equipment, manpower, and munitions. Estimates of each cost element are generated by multiplying key parameters of the new weapon system program such as number of program flying hours, number of weapons to be purchased, or flyaway cost, by a factor which is derived as a function of Air Force cost experience on similar weapon systems. In many cases this factor is developed by statistical regression. For example, the factor, replenishment spares cost per flying hour (RS$/FH), might be computed as a function of avionics production cost, engine production cost, airframe production cost, maximum aircraft speed, and aircraft empty weight. The form of this function may vary, e.g., linear form, log form, etc., and its coefficients are typically determined by fitting it to historical data on RS$/FH, avionics cost, engine cost, etc., for similar weapon systems formally or currently in the Air Force inventory. These estimating relationships continue to be revised as new historical data becomes available.

In recent applications of this estimating technique, several advancements have been made. First, estimates are now time phased by year to reflect the impact on cost of the phasing of military equipment into and out of the Air Force inventory. Second, the phenomenon of learning during the base and depot level maintenance of Air Force equipment is now reflected through the use of an "improvement curve" which is analogous to the "learning curves" historically used in production cost estimating. Some specific cost factor models are briefly described in the next three paragraphs.

1.2 The BACE (Planning, Programming, and Budgeting Annual Cost Estimating) Model

This model utilizes an Air Staff coordinated methodology to develop O&S cost estimates for active, guard, and reserve forces. It has been

used in planning, programming, and budgeting exercises and in the development of O&S cost estimates with respect to the A-10 Defense Systems Acquisition Review Council (DSARC) III, the F-15 DSARC IIIA, B and C and the F-16 DSARC II.

1.3 The CACE (Cost Analysis Cost Estimating) Model

This model was developed to be flexible enough to permit a variety of types of studies. In addition, it will serve as a vehicle for introducing new factors and estimating techniques. The CACE model can be used for research analyses and in studies involving cost effectiveness comparisons between weapon systems.

1.4 The MACE (Missile Annual Cost Estimating) Model

This model is similar to the CACE model except that it has been developed for use in costing missile squadrons.

1.5 Cost Factor Model Attributes and Limitations

A prime attribute of the cost factor model approach is ease of model use. The supporting data base of cost factors used with the model can be updated periodically to reflect the Air Force's more recent O&S cost experience. However, a limitation of the approach is that the cost factors used are aggregate values reflecting whole weapon system cost elements as opposed to subsystem cost elements. Thus, because it does not explicitly break out costs in detail at the subsystem and line replaceable unit (LRU) level, this approach tends not to capture the O&S cost impact of individual reliability and maintainability (R&M) characteristics of a peculiar new weapon system.

2. ACCOUNTING MODELS

2.1 Background

The accounting model is one of the most familiar types of O&S cost models. It typically computes O&S costs at relatively low levels of hardware breakdown and disassembly, e.g., the line replaceable unit (LRU) level, and then totals these costs. Components of O&S cost computed at this level include initial and replenishment spares costs, on- and off-equipment maintenance cost, inventory entry and supply management costs, support equipment cost, cost of personnel training and training equipment, cost of management and technical data, and cost of new facilities. Four categories of input parameter estimates are typically required:

(1) Program elements. Data characterizing the overall program such as flying hour program, schedule and development scenarios which are furnished by the Government.

(2) Contractor-furnished subsystem elements. Estimates of costs that are not directly associated with LRUs, but nonetheless contribute significantly to overall system cost, such as special depot facilities costs.

(3) Contractor-furnished LRU elements. Estimates of parameters that are based on characteristics of the design of the LRU, such as mean flying time between maintenance action.

(4) Government-furnished standard elements, such as labor rates, inventory costs, and repair cycle times.

Accounting models have historically been used by the Air Force with respect to source selection and design tradeoff decisions. Five currently available accounting models are discussed in sections 2.2-2.6.

2.2 The AFLC Logistics Support Cost (LSC) Model*

The objective of the AFLC Logistics Support Cost (LSC) model is to estimate the support costs that may be incurred by adopting a particular design for a given weapons system or piece of equipment. "The model is intended for application in two areas: (1) to obtain an estimate of the differential logistics support costs between the proposed design

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* See the "Logistics Support Cost (LSC) Model User's Handbook", published by AFLC/AQMLA, Wright-Patterson AFB, Ohio 45433.

configurations of two or more contractors during source selection; and (2) to serve as a decision aid when discriminating among design alternatives during prototyping for full-scale development."

The LSC model consists of ten equations or submodels, each of which represents a component of the total cost of resources necessary to operate the logistics system. The ten cost components are:

(1) Initial and replenishment LRU spares cost.

(2) On-equipment maintenance cost

(3) Off-equipment maintenance cost

(4) Inventory entry and supply management cost

(5) Support equipment cost

(6) Cost of personnel training and training equipment

(7) Cost of management and technical data

(8) Facilities cost

(9) Fuel consumption cost

(10) Cost of spare engines

The first seven cost components are evaluated for each appropriate LRU and the results are aggregated over all subsystems. To arrive at a logistics support cost for the total system, the last three components are added.

The LSC model has been used both in the source selection environment and within the design tradeoff environment. It has been used in two ways during source selection evaluation: (1) as a framework for development of an LSC estimate to be used as a source selection evaluation criterion, and (2) as a framework for development of a target logistic support cost (TLSC) which, in turn, serves as the basis for a contractual commitment. Each of these cases is described below.

An LSC Estimate as a Source Selection Evaluation Criterion

In this case, the LSC model is typically tailored by the program office to fit the equipment being considered for purchase and then

transmitted to all competing contractors along with values of Government supplied model standards and constants. Each contractor then develops his best estimate of logistic support cost using the model framework and his best estimates of equipment input parameters such as mean time between failure (MTBF), mean time to repair (MTTR), etc. Subsequently, these estimates serve as one of several source selection evaluation criteria with respect to each bidder's equipment. In addition, the contract frequently includes a provision for a field verification test during which observations of MTBF, MTTR, etc., are collected and input to the model, resulting in a revised estimate of logistic support cost. An additional incentive fee can be awarded to the contractor in the event that the revised LSC estimate is less than or equal to the original source selection LSC estimate.

The LSC model is being used in this way with respect to the F-16 aircraft. The original LSC estimate in this case is referred to as the system level target logistic support cost (TLSC) and the revised estimate based on field observations, is called the measured logistic support cost (MLSC). Each of these estimates is a summation of LSC estimates for about 300 F-16 LRUs and an incentive fee of $6.4M is awardable if the system level MLSC is less than or equal to the system level TLSC. This type of model is being used in source selection for the high technology ejection seat (HTES) program as well as several other items of equipment currently being procured by the Aeronautical Systems Division.

The LSC Model in a Contractual Commitment

The F-16 aircraft also serves as a good illustration of the use of the LSC model in connection with contractual commitments. For a selected set of twelve high life cycle cost line replaceable units including the inertial navigation system, flight control computer, fire control computer and attack radar, designated as contractor first line units (FLUs), a shortened form of the LSC model involving only spares cost, on-equipment maintenance cost, and off-equipment maintenance cost is being used as a framework for computation of a target logistic support cost (control FLU TLSC). During a 3500 flying hour test under field conditions, revised estimates of key model input parameters will be calculated based on field observations, resulting in a revised estimate of control FLU logistic support cost, called control FLU MLSC. There exists an award fee of up to $2M if the control FLU MLSC is less than or equal to the control FLU TLSC. However, if the MLSC is greater than 1.25 times the TLSC, the contractor must take action, partially at his own expense, to improve the logistics performance to the satisfaction of the Air Force. This is referred to contractually as a Correction of Deficiencies (COD) action and the overall contractual arrangement involving the TLSC, MLSC,

award fee, and COD provision is called a Logistics Support Cost Commitment (LSCC).

Also, there typically exists a contractor charge, called the COD target price, which is a negotiated dollar amount for each control FLU paid by the Air Force for technical risks assumed by the contractor under the LSCC. Each contractor's bid values for the TLSC and COD target price can serve as indicators during source selection evaluation of the contractor's perception of (1) his ability to deliver highly supportable equipment to the Air Force and (2) the technical risks involved in pursuing this goal. After a contractor is chosen for equipment full-scale development and production, this commitment provides a continuing motivation to the contractor throughout most of the production phase to make his equipment highly reliable and maintainable.

There also currently exists an LSC commitment on the ARN-101 tactical LORAN currently being procured by the Electronic Systems Division at Hanscom Air Force Base, Massachusetts. A somewhat similar contractual commitment is being used on the ARC-164 UHF radio program, currently being procured by the Aeronautical Systems Division. The positive and negative incentives for this item are different in structure from those in the LSC commitment but provide essentially the same kind of motivation for the contractor. Life cycle cost estimates were the primary basis for selection of the ARC-164 production contractor.

The LSC Model and Design Tradeoffs

The LSC model has been used to some extent to examine the impact of alternative equipment designs on various components of logistic support costs. Recent examples include use of a modified form of the model (1) by the B-1 aircraft avionics subcontractor to compare alternative avionics packages on the basis of support resource impact and (2) by the B-1 and A-10 prime contractors to compute the effects of proposed engineering change proposals (ECPs) on estimated life cycle costs.

2.3 The AFLC Operations and Support (O&S) Cost Model

The AFLC O&S cost model is very similar to the AFLC LSC model. Both models compute O&S costs as a function of logistics and program parameters. They differ in minor respects, e.g., the LSC model breaks down cost to the LRU level for AGE whereas the O&S cost model does not.

The O&S cost model was used with respect to full-scale development source selection on the A-10 Program. *

2.4 A Life Cycle Cost Model for Inertial Navigation Systems**

A problem frequently discussed with respect to accounting models is the lack of standardization in the way cost elements are defined and in the level of detail at which costs are isolated from one accounting model to the next. This lack of standardization can cause difficulty when comparisons of O&S cost estimates for a given system or equipment are called for and must be derived from two or more models. In recent years, an effort to overcome this problem has been underway in the field of inertial navigation. In August 1973, a Life Cycle Cost Task Group was chartered by the Joint Services Data Exchange Group for Inertial Systems (JSDE/IS), a collection of inertial system technical community representatives organized in 1969 and authorized by the Joint Logistics Commanders. A key objective of the LCC Group was to develop and implement a standard LCC model for inertial systems to be used by industry and government for the evaluation of alternative equipment designs on the basis of predicted life cycle costs. Model development has proceeded since that time and should be complete by the Fall of 1976. A computer card deck and model user's manual will be available at this time to all potential model users.

During development of the INS LCC model, considerable emphasis was put on the use of definitions and computational algorithms that could be readily understood and agreed to by potential model users. The model includes eight different output reports: one relfecting input data, three reflecting background data, and four reflecting cost data. This attribute should significantly enhance the model's usefulness to a wide spectrum of members of the INS community.

The model subdivides equipment life cycle cost into its three components -- cost of research, development, test, and evaluation (RDT&E), cost of acquisition, and cost of operation and support (O&S) -- and further subdivides within each of these components. RDT&E cost is broken into costs of:

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* A full description of this model is included in a report entitled "Review of the Application of Life Cycle Costing to the A-X/A-10 Program (1970-1973)", prepared by a study team under the direction of the Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost, ASD/ACL, Wright-Patterson AFB, Ohio 45433, October 1973.

** Further information with respect to this model can be obtained from Mr Russell B. Stauffer, J&R Associates, Box 58, Jackson, N.H. 03846 (phone 603/383-6883).

(1) Conceptual studies

(2) Design engineering

(3) Testing

(4) Technical Publications during RDT&E

(5) Software

(6) Training during RDT&E

(7) Engineering change proposals (ECPs)

(8) Program management

(9) Test hardware

(10) Test spares

(11) Test equipment for the test program

(12) Training devices

(13) Personnel associated with training during RDT&E

(14) Contractor program management

(15) Government program management

Each of these elements is broken down still further. Acquisition cost is broken into costs of:

(1) Production tooling and test equipment

(2) System recurring acquisition

(3) Equipment installation

(4) Production program start-up

(5) Support equipment acquisition

(6) Technical data

(7) Training equipment

(8) Spares, including O& S parts and material

(9) Maintenance management data

(10) Inventory management

As the model gains acceptance throughout the INS community, it is expected that a small committee of JSDE/IS personnel will be formed to serve as an LCC model monitor. This group will have the responsibility of considering/approving/disapproving suggested modifications to the model. This approval mechanism should ensure that the model retains its identity as a generally accepted standard LCC analysis framework as changes over time in INS technology precipitate changes in model algorithms and formats.

2.5 A Life Cycle Cost Model for Aircraft Engines*

Due to the technical complexity and complex wearout characteristics of Air Force turbine engines during recent years, the task of predicting turbine engine life cycle costs has been most difficult. In mid-1975, a Joint Industry-Air Force Life Cycle Cost Methods Improvement Group was initiated by the Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost to address problems associated with engine LCC prediction and LCC tradeoff techniques. The Group included representatives from all major engine manufacturers and members of the engine research, engineering, and cost communities at the Aeronautical Systems Division (Wright-Patterson AFB). Initial Group discussions led to a decision to undertake the development of a Joint Industry-Air Force Engine LCC Model for use with respect to future aircraft engine source selection evaluations. Model development proceeded through several Group meetings in late 1975 and early 1976. A final copy of the model was distributed to Group members in April 1976.

The model framework covers the RDT&E, acquisition, and O&S components of LCC and breaks these components out in a manner very similar to the INS LCC model described in section 2.4. Sources of all required input data elements, e.g., engine contractor, AFLC standard, program office, using command, etc., are identified in the model

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* Further information about this model and its development can be obtained from Mr Richard M. Ellis, ASD/ENO, Wright-Patterson AFB, Ohio 45433 (phone 513/255-2570/3979).

description. In addition, a set of "cost drivers" is identified with respect to each major cost element. For example, delivery quantities, rates, rate changes, and lead times are identified qualitatively in the model as some of the factors that have a primary influence on tooling cost. Although such factors are not quantitatively linked to tooling cost within the model, they provide, a priori, a set of agreed upon criteria to which contractors can refer in defending the model cost element projections contained in their equipment proposals.

Considerable effort was made during model development to realistically reflect costs of scheduled and unscheduled engine maintenance. Efforts were also undertaken to make the RDT&E and acquisition portions of the model compatible with standard Air Force Work Breakdown Structures (WBS) as defined in MIL STD 881.

The model description includes a set of general instructions that describes government and contractor responsibilities with respect to model use. It is anticipated that the model will be implemented with respect to all major engine procurements at the Aeronautical Systems Division in the future.

2.6 SIMPLIFIED MAINTENANCE COST MODEL*

The simplified model requires only six input data parameters:

(1) Mean time between failure (MTBF).

(2) Mean time between other-than failure-related maintenance actions (MTBMA).

(3) Cost per failure.

(4) Cost per non-failure-related maintenance action.

(5) Quantity per application.

(6) Force flying hours.

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* Additional information can be obtained from ASD/ACL, Wright-Patterson AFB, Ohio 45433. When the new data system described above becomes available, a report will be prepared on both the data system and use of the simplified maintenance cost model.

The model will compute the total, annual and unit annual maintenance costs depending on the flying hour values used to input the model and list the maintenance costs for each component or subsystem, from the most expensive to the least expensive.

The simplified maintenance cost model has three major potential uses. First, it can be used to compare maintenance cost estimates for proposed designs with actual maintenance costs of existing designs. Such comparisons can be used for source selection evaluation guidance or any other evaluation where relative rather than absolute maintenance cost estimates are useful. The word "relative" is emphasized here because, among other reasons, there presently exists little field experience data on base material costs, one of the components of the cost per failure figure used in the model. Second, the simplified model can be used to assess the maintenance cost implications of test results and then used to track estimated maintenance costs of new equipment. Third, since the model separates those costs attributed to actual failures from those attributed to other maintenance actions, it goes one step beyond the current K051 (IROS) data system. This additional piece of information should prove useful in pinpointing whether high support costs are the result of poor reliability or non-failure-related problems.

2.7 Accounting Model Limitations

Most accounting models have some significant limitations, several of which need to be overcome if models of this kind are to gain wider acceptance in the future.

A principal weakness is the lack of a reliable and accurate set of historical data to estimate support costs at the component level on an analogous basis. This problem is due in part to the fact that the multiple data systems used by AFLC are designed for purposes other than weapon system cost accounting. For example, the base level maintenance data collection system is largely a production control monitoring and scheduling system. Because of these diverse sources of data, only partial weapon system support cost visibility is to be found at best, and a great deal of prorating of common expenses applicable to several weapon systems exists. A companion problem exists in the practice of managing both depot level maintenance and supply by National Stock Number (NSN), base level supply by NSN, and base level maintenance by Work Unit Code (WUC). The fact that there is no direct one-to-one mapping of NSN to WUC further

aggravates the data problem, especially at the component level.* These problems together with the fact that this kind of model typically requires large numbers of input data elements can make model implementation a tedious exercise. In the case where a model generated estimate serves only as a source selection evaluation criterion and there is no direct cost to the contractor if the logistic support costs of his equipment overrun with respect to this target, the credibility of the model estimate becomes critically dependent on the ability of the government user to scrutinize and validate all model input estimates. If, due to difficulties in collecting input data under source selection time constraints, government personnel are unable to satisfactorily carry out this task, the model output estimate cannot be relied on and it may have little utility as a source selection evaluation consideration.

Another limitation of most accounting models exists with respect to design tradeoff applications. Accounting models tend to have limited usefulness here because they ordinarily compute logistic support cost as a function of R&M parameters such as mean time between failures and maintenance manhours per flying hour. They do not relate logistic support costs directly to performance and design parameters such as material types, dimensions, speed, and range. Therefore, they cannot be used early in conceptual planning when tradeoffs of this nature are usually made. This point is of particular concern since these early tradeoff decisions frequently have a large impact on O&S costs.

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* DOD has recognized these difficulties and is attempting to make improvements. In January 1974, a task group on "Visibility and Management of Support Costs" was chartered by Deputy Secretary of Defense Clements to develop a system to identify maintenance and operations costs by weapon system. In addition, the Air Force has developed a Base Maintenance Collection System intended to identify several elements of base-level costs at the mission, design and series (MDS) levels. Implementation of this system was begun in July 1975. Efforts are also underway in the Air Force Logistics Command (AFLC) to:

- Allocate component and engine depot repair costs to the MDS.

- Examine procurement appropriation costs to determine the feasibility of identifying more of these costs to weapon and support systems.

- Match operations and maintenance resources now identified to AFLC organizations with weapon and support systems.

There currently exist few models relating elements of operating and support cost to design parameters. The little research that has been done in this area indicates that such models are difficult to develop. Furthermore, they must usually be tailored to specific categories of defense equipments. Nonetheless, the fact that significant reductions in system and equipment life cycle cost may be realizable from more explicit consideration of O&S costs during early design studies strongly suggests that more research should be done in this area.

3. COST ESTIMATING RELATIONSHIP MODELS

3.1 Background

Statistical cost estimating relationships (CERs) are mathematical equations that express the total or specified partial cost of a system or equipment directly as a function of (1) physical properties (e.g., accuracy, volume, or parts density) of the system/equipment or (2) properties of the operating environment in which the system/equipment will be used (e.g., deployment scenario, flying hour program, or aircraft environment). They are typically derived by using statistical regression to fit cost data on existing similar systems/equipments to the data that reflect physical or environmental properties for these systems and equipments. Their advantage over accounting models is threefold: (1) They can be developed and used early in the conceptual and preliminary design stages of RDT&E to study the effects on cost of varying these properties and hence to compare alternative requirements on the basis of cost. (2) They can be used to obtain preliminary estimates of cost when details of design or operating and support concepts are not yet known. (3) They generally require much less input data than accounting models and can be more easily used for sensitivity or parametric analysis.

Cost estimating relationships have frequently been used in recent years to estimate the development and production costs of new Air Force equipments. However, there is little experience to date in the use of CERs to estimate the various different components of operating and support costs or to estimate costs of reliability improvement. Such CERs are needed to enable decision makers to more explicitly consider the impact of alternative design concepts on operating and support costs and to determine equipment reliability design goals that result in reduced life cycle costs. The models described below represent initial efforts to derive relationships of this type.

3.2 A Cost Estimating Relationship for Predicting the Quarterly Maintenance Cost of an Inertial Measurement Unit*

The underlying objective in the development of this CER was to

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* For a more detailed description of this CER and its development, see "Cost Estimating Relationships for Predicting Life Cycle Costs of Inertial Measurement Unit Maintenance", (SLSR 16-75A) a thesis in the School of Systems and Logistics of the Air Force Institute of Technology by Lt Lynn M. Lynch and Capt Neil V. Raymond, January 1975 (DDC #ADA006344).

demonstrate that maintenance costs of inertial measurement units (IMUs) could be predicted strictly as a function of design and policy data that would be available to planners during the conceptual phase of weapon system acquisition. The estimated cost (dependent variable) in the CER is the average quarterly maintenance cost per aircraft. The estimating (independent) variables were selected based on two criteria: (1) Is the variable one that, viewed logically, would affect maintenance costs, and (2) is the variable one that would be known to planners in the conceptual phase of weapon system acquisition? The resulting CER has the general form,

$$y = a + bx_1 + C \ln x_2 - dx_3 - ex_4 + fx_5 + gx_6$$

where

y = quarterly IMU maintenance cost per aircraft

x_1 = precision, z axis gyro, in degrees of allowable random error per hour

x_2 = average quarterly flying hours per IMU

x_3 = type slaving system (north slaved or free azimuth)

x_4 = number of aircraft in the inventory which have the IMU installed

x_5 = precision, north or east axis gyro, in degrees of allowable random error per hour

x_6 = mean time between demands for the IMU in flying hours and a, b, c, d, e, f, and g are appropriate constant values.

The CER was developed by the ordinary least squares method of multiple regression analysis and a fairly high level of statistical validity was attained (coefficient of determination, $R^2 = .8339$). The data used for the estimating variables was extracted from empirical data on ten aircraft IMUs in the Air Force inventory during fiscal years 1973 and 1974. Maintenance cost data included (1) field level data collected by Work Unit Code (WUC) from the Increase Reliability of Operational Systems (IROS) data format (more specifically, the K051.PN4L report) and (2) depot level data from the Depot Maintenance Industrial Fund (DMIF) Monthly Operating Gain or Loss Statement at the only depot that services IMUs, the Aerospace Guidance and Metrology Center (AGMC) at Newark, Ohio.

The data used to derive this CER was of good quality relative to maintenance cost data on Air Force equipment in general and the CER development effort was rigorously carried out. However, the resulting CER has a weakness which, in the opinion of this author, tends to illustrate how difficult it can be to develop meaningful and useful O&S CERs. Namely, the CER suggests that maintenance cost increases as mean time between demand (MTBD) increases, a result which most people familiar with the maintenance process find counterintuitive. The thesis authors suggest that this result may be driven by the greater expenditure of depot funds on quality control, more highly qualified technicians, and more expensive parts on those IMUs with the higher reliabilities, an argument which has some merit but is regarded as weak by most. The CER is intuitively acceptable in every other way and, except for this weakness, could be useful to conceptual stage policy planners as a tool for gaining insight into the maintenance cost impact of basic alternative operational and design scenarios. However, to date, the author has been unable to find any efforts to use the CER in this environment.

3.3 Statistical Relationships for Estimating Cost of Reliability Programs*

The purpose of this CER development program was twofold: (1) to provide a quantitative basis for estimating costs of reliability design programs, reliability parts programs, and reliability testing programs so that these costs can be more explicitly considered and accurately estimated when budgeting for the development of avionics equipment, and (2) to provide a method for giving visibility to the costs of achieving given levels of avionics equipment availability.

Four basic types of relationships were developed during this effort:

(1) Total reliability program cost (in man-days) as a function of resultant equipment MTBF and number of electrical parts in the equipment.

(2) Cost of reliability design program, reliability parts program, and reliability test program, each as a function of number of electrical parts.

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* Reliability Acquisition Cost Study, General Electric Company, (Salvatore P. Mercurio and Clyde W. Skaggs), contract F30602-72-C-0226, Project 5519, Job Order No. 55190256, prepared for RADC (RBRS), Griffis AFB, New York 13441 (contract monitor - Mr Jerome Klion).

(3) Resultant equipment MTBF as a function of reliability parts program cost, reliability test program cost, and number of electrical parts.

(4) Incremental increase in reliability program cost as a function of incremental increase in MTBF.

The relationships were developed using data from two manufacturers on ten equipments. Both aircraft and space equipments were considered. The reliability design program was assumed to include prediction, failure modes and effects analysis, and design reviews; the parts program was assumed to include parts screening specification, parts standardization and control, and vendor control; and the reliability test program was assumed to include evaluation testing, equipment environmental screening, and reliability demonstration testing.

These relationships can be used in tradeoff and life cycle cost analyses to provide a heretofore missing link, namely, a relationship between reliability development cost and resulting reliability. They can also be used to determine the optimum size and mix of reliability program elements in any development environment that is similar to the one from which data for this study was gathered.

To date, there has been virtually no experience in using these CERs in design of new reliability programs. However, there are plans to use them at two levels:

(1) The General Electric Company plans to use them to structure reliability programs and estimate reliability program costs in future avionics development efforts.

(2) In its capacity as monitor of several reliability programs at ASD and ESD, RADC plans to use the CERs to estimate the costs associated with these programs and to evaluate the levels of reliability improvement that are achievable with given levels of program funding.

In addition to these planned efforts, it is also hoped that analysts associated with program offices will take the initiative to use the CERs in designing and budgeting for avionics reliability programs associated with their systems.

3.4 Relationships for Predicting Reliability*

Most accounting models in the O&S cost estimating literature today break down the various components of O&S cost as a function of a variety of program parameters such as peak force flying hours per month and logistics parameters such as mean time to repair (MTTR) and mean time between failures (MTBF). Furthermore, because the parameter, MTBF, plays such a central role in most accounting models, uncertainty in the input estimate of MTBF can result in considerable uncertainty in the output estimate of total O&S cost. Hence, it is important to minimize uncertainty in the MTBF estimate, a task which can be most difficult during conceptual and preliminary design stages of development when little more than basic equipment design characteristics may be known.

An interesting approach to this problem was developed recently in a study undertaken by Hughes Aircraft Company for Rome Air Development Center. In this study, Hughes developed a set of statistical relationships which estimate MTBF as a function of key equipment design parameters. Multiple linear regression analysis was used to develop relationships for each of four classes of avionics equipment: radars, computers, displays, and communications. In all cases, the estimating (or independent) variables were parameters for which values are usually known during conceptual or early planning and design phases. For example, the relationship for airborne computers has the form,

$$
\begin{aligned}
\ln (1/\text{MTBF}) = a &- b\ (\text{design year}) \\
&- c\ (\text{add/subtract time}) \\
&+ d\ (\text{power dissipation}) \\
&- e\ (\text{number of instructions}) \\
&+ f\ (\text{add/subtract time})\ (\text{number of instructions}) \\
&- g\ (\text{memory speed})\ (\text{power dissipation})
\end{aligned}
$$

Where a, b, c, d, e, f, and g are constants describing the model,

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* Study of Reliability Prediction Techniques for Conceptual Phases of Development, Hughes Aircraft Company (L. E. James, T. S. Sheffield, and K. M. Plein), contract F30602-73-C-0180, job order no. 55190263, prepared for RADC (RBRS), Griffiss AFB, New York 13441 (contract monitor - Mr Jerry F. Lipa).

the list which follows this paragraph shows the entire set of estimating variables for each equipment class. The percentage of variation (R^2) accounted for by these sets of variables was generally high, ranging from 76% to 94%.

The study also developed (1) relationships for estimating parts count as a function of the variables shown below and (2) a method for finding a lower one-sided confidence interval both for a failure rate estimate and a parts count estimate. It included a variety of examples to show how these point and interval estimating expressions can be used in evaluating alternative equipment designs.

RELIABILITY INDICATORS

Radars
- Multiple Target Resolution (KFT)
- Detection Range (NMI)
- RF Peak Power (KW)
- Pulse Width (SEC)
- Antenna Gain (dB)
- Half Power (Az deg)
- Receiver Dyn Range (dB)
- Noise Figure (dB)

Computers
- Memory Speed (SEC)
- Multiple Time (SEC)
- Divide Time (SEC)
- Memory Access Time (SEC)
- I/O Transfer Rate (KWORDS/SEC)
- Power Dissipation (W)
- Number of Instructions
- Add/Subtract Time (SEC)

Displays
- Write Speed (IN/ SEC)
- Power Dissipation (KW)
- Display Area (IN^2)
- Settling Time (SEC)
- Spot Size (IN)

Communications
  Transmit Level (W)
  Receive Level (dBM)
  Receiver Bandpass (dB)
  Receiver Bandwidth (KHZ)
  Prime Power (KW)

3.5 Relationships for Estimating Operating and Support Costs of Avionics Equipment*

In this study, several cost estimating relationships (CERs) were developed for the purpose of forecasting yearly maintenance cost as a function of purchase price and certain design parameters such as mean time between failure (MTBF) and peak operating power. The study also developed factors for estimating initial spares cost and AGE and AGE spares cost as a percentage of equipment investment cost. Sources of data for the study included RADC, IDA, ARINC, and AFLC. A primary problem encountered during this effort was considerable noise in, i.e. uncertainty in the validity of the maintenance cost data. This caused several of the resulting CERs to have lower coefficients of determination than desired. Nevertheless, annual maintenance CERs for doppler and fire control radars and bomb-nav systems exhibited adequate coefficients of determination and standard errors.

A follow-on contract is underway to develop a more comprehensive set of CERs in this area.** Particular attention will be given to more extensive use of MTBF and other design parameters as independent variables in these studies. Equipments to be considered include radar warning receivers, electronic countermeasures pods, inertial measurement units, radars, TVs, lasers, and computers.

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* Cost Analysis of Avionics Equipment, Air Force Avionics Lab (AFAL) Technical Report 73-441, February 1974. This study was done for AFAL by General Research Corporation and was directed technically by Major Richard Grimm.

** The Project Engineer for this contract was Captain Lee Darlington, AFAL/AAA-4, Wright-Patterson AFB, Ohio 45433.

3.6 A Modular Cost Estimating Relationship Model for Life Cycle Costs of Advanced Systems*

This model consists of a large collection of CERs currently under development by Grumman Aerospace Corporation in conjunction with Lockheed Aircraft Corporation for the Air Force Flight Dynamics Laboratory. It is one of the first efforts to attempt to develop LCC CERs for all the major subsystems of Air Force aircraft. Examples of subsystems to be addressed on an individual basis are wing, body, tail, pylon/nacelle, flight control subsystem, fuel control subsystem, hydraulic/pneumatic subsystem, landing gear subsystem, communications subsystem, interphone, IFF, fire control, weapon delivery, radio navigation, aircraft engine, etc. For each of these subsystems, the RDT&E, production, and O&S components of LCC will be addressed separately. Within the category of production costs, the following kinds of cost will be addressed individually: production hardware, support equipment, initial spares, technical publications, training equipment, and training. Within the category of O&S costs, the following areas will be individually addressed: base level personnel, replenishment spares, depot level maintenance, and fuel.

The objective of this CER development effort is to provide a set of tools for evaluating the impact of competing design alternatives during the early stages of an aircraft development effort on the basis of life cycle cost and at a subsystem level. Accordingly, an attempt will be made to ensure that estimating or independent variables in these CERs will be the primary parameters in terms of which early design decisions are made.

3.7 Accounting Models Versus Statistical Cost Estimating Relationships: A Multidisciplinary Approach

The question of when accounting model techniques versus statistical cost estimating techniques can most effectively be used to estimate O&S costs has received considerable attention by cost analysts in recent years. It is generally agreed that CERs are to be used during early development program phases when little detail about new equipment is known and that at some point during the program, CERs can be replaced by accounting models. But analysts have had difficulty implementing this approach with respect to O&S costs mainly because it has not yet been clearly demonstrated

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* Since work under this contract has only recently begun, there is virtually no descriptive material on this model available at present. However, questions about the model can be referred to the contract monitor, Mr Nathan Sternberger, Air Force Flight Dynamics Laboratory, AFFDL/FXC, Wright-Patterson AFB, Ohio 45433 (phone 513/255-4517).

that sufficiently accurate and workable CERs can be developed for use during early development phases. Consequently, the tendency has been to ignore the possible use of CERs and to use accounting models even in very early development stages in spite of the fact that great uncertainty in accounting model input parameter estimates is inevitable in these cases.

A more useful approach may be to think in terms of concurrent use of the statistical estimating approach and accounting model approach throughout the development and acquisition cycle as illustrated by the sequence of tree structures in Figure 3.7.1. When the concept for a new piece of military equipment is first defined, perhaps it is practical to address the life cycle cost of the equipment only in terms of its RDT&E, production, and O&S cost components. These three cost components can be thought of as the three cost elements of a dynamic accounting model framework which increases in detail over time. At this point LCC might be estimated using three CERs -- one for equipment RDT&E cost, one for production cost, and one for O&S cost. As the development program progresses, the equipment can be defined in more detail and accounting model cost elements can be subdivided into a greater number of cost elements. For example, it may become feasible to address O&S costs in terms of equipment maintenance cost, support equipment cost, and spares cost as illustrated by the second tree from the left in Figure 3.7.1. Finally, as the equipment gains more and more definition, it may become appropriate to explicitly address relatively detailed elements of life cycle cost with respect to each of several individually definable parts of the equipment.

Figure 3.7.2 illustrates how various existing accounting models and CERs might fit into this dynamic LCC model framework. Historically, very gross CERs such as those developed for engines in recent years by RAND Corporation personnel are used during the conceptual stage.* As the development program progresses, the accounting model gains in detail and CERs that specifically treat subelements of LCC (e.g., the IMU maintenance cost CER and the Grumman CERs) can be used. Finally, full-scale accounting models such as the INS LCC Accounting Model, Engine LCC Accounting Model, and AFLC LSC model (described in Appendix 2) can be used. At this point it may be advantageous to use estimating relationships to determine values for many of the accounting model input

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* Examples of these CERs are developed in Relating Technology to Acquisition Costs: Aircraft Turbine Engines (R-1288-PR) by J.R. Nelson and F.S. Timson, The RAND Corporation, 1700 Main Street, Santa Monica, California 90406, March 1974.

parameters (e.g., the Hughes relationships for MTBF).

Experience during the next few years with accounting models and statistical estimating techniques described above should provide considerable insight regarding just how practical and useful this concurrent approach is in a real-world cost estimating or design tradeoff environment.

FIGURE 3.7.1

A DYNAMIC LCC MODELING FRAMEWORK (1)

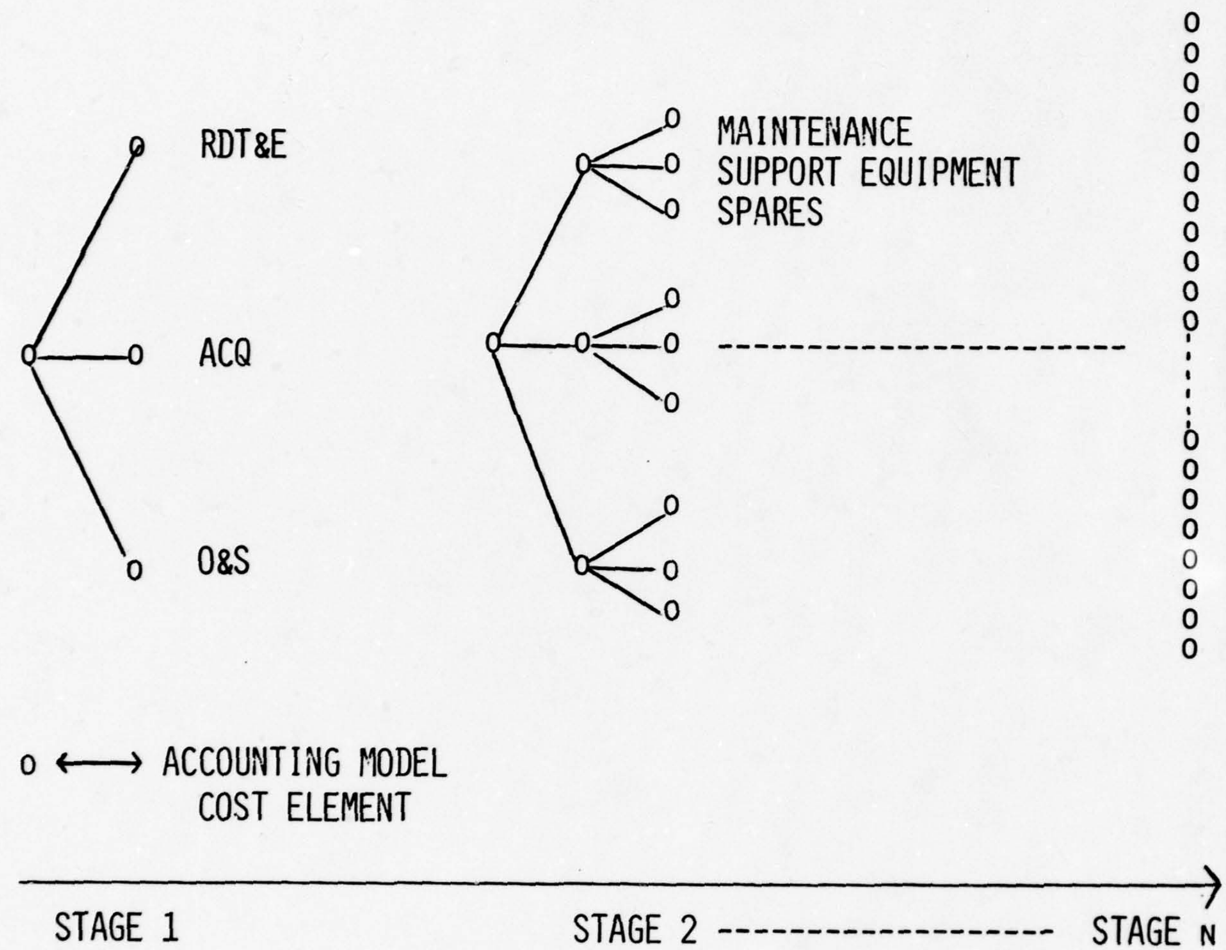
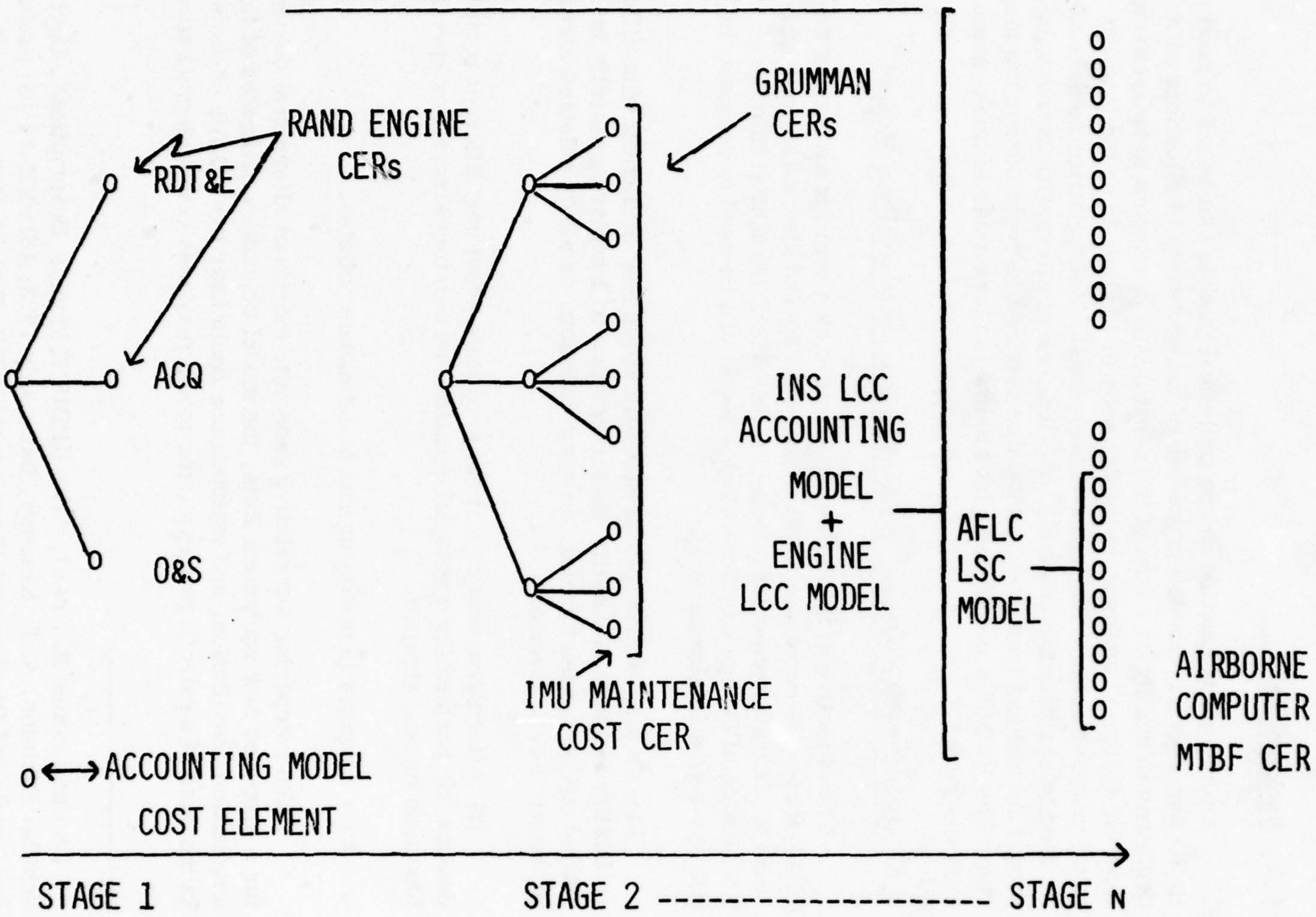


FIGURE 3.7.2

A DYNAMIC LCC MODELING FRAMEWORK (2)



4. ECONOMIC ANALYSIS MODELS

4.1 Background

An important function where analytical models can be put to good use in the Air Force is the determination of the economic implications of decisions to modify or augment the capabilities of current weapons systems. Retrofit decisions typically raise the issue of whether to spend funds in early years to achieve savings in later years. Mathematical models can be used to evaluate the economic implications of alternative retrofitting programs and can lead to decisions that reduce life cycle cost in the long run. The REDUCE model described below is an example of an economic analysis model.

4.2 REDUCE: An Aircraft Subsystem Economic Analysis Model*

The objective of this model is to serve as a tool for evaluating the USAF forcewide economic implications of proposed alternative new and retrofit aircraft equipment programs. REDUCE (Research into the Economics of Design and User Cost Effects) can be used to compute the life cycle cost implications of:

(1) An aircraft retrofit program in which new equipment with different reliability and maintainability characteristics will replace presently installed equipment performing the same function, on all or selected aircraft in the Air Force inventory.

(2) Alternative new equipment proposals providing different equipment designs for performing additional functions on existing aircraft or specific functions on new aircraft.

(3) Changes in operating and maintenance policies.

When comparing the relative economic merits of alternative designs for a proposed new equipment item, the model considers estimates of RDT&E, acquisition/installation, and maintenance costs over the full life of the system. In the case of a retrofit program, the model produces comparisons between

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* Cerone, James R., et al, "The REDUCE Model: Description", Caywood-Schiller Division, A.T. Kearney, Inc., July 1972; ASD/XR-72-34; prepared for Deputy for Development Planning, ASD/XR, Wright-Patterson AFB, Ohio 45433. For additional information contact ASD/ACL, WPAFB, Ohio.

the life cycle costs of a proposed new item and the support costs of the items it would replace. It also provides the capability for exploring tradeoffs between the investment of money in RDT&E to improve an item's reliability and maintainability characteristics and consequent savings in maintenance costs during the item's operating lifetime. The model uses discounting procedures to calculate the present values of future program costs and also has the capability to consider inflation and estimate out year costs in then-year dollars. It provides a variety of output formats designed for both budget and decision analysts.

The model is composed of the following major components:

(1) A data base needed to describe the scope of future operations; the equipment configuration of each aircraft series to be considered for retrofit; and reliability, maintainability, and cost factors of equipment items currently installed in these aircraft.

(2) The INIT module which establishes a data base in a computer storage-compatible format initially and updates the data base after it has been established.

(3) The ACOUT module which produces output formats containing information required to make decisions concerning item replacement.

(4) The SETUP module which transforms inputs on a proposed new item into computer records that can be operated on by other modules.

(5) The RETROFIT module which evaluates the life cycle cost effects of proposed retrofit programs.

(6) The NEW vs NEW module which computes and compares the life cycle costs of several alternative new items being considered for performing a given function.

The model requires considerable input data. The effort required to obtain this data is most easily justified for a complex problem involving the possible use of a new improved piece of equipment on several aircraft types over a long period of time. It is ideally suited to economically evaluate the potential value of standardization of new and low maintenance cost subsystems throughout the Air Force.

5. LOGISTIC SUPPORT COST SIMULATION MODELS

5.1 Background

In recent years, the Air Force and aircraft industry have developed a variety of computer simulation models for use in logistic support planning. In general, these models explicitly address all aspects of logistics operations including the flying schedule, basing concept, maintenance plan, and spare and support resource requirements. They frequently require extensive amounts of input data. In addition, they include a variety of output reports that give detailed statistics in each of these areas. Such statistics are frequently used in trade studies and system validation tasks.

Historically, these models have usually collected some statistics with respect to initial investment and O&S costs, but for the most part, their orientation has not been specifically to life cycle cost but rather to the much broader set of tradeoff issues included under the heading of logistic support planning. In the last year or two, however, there has begun to be a more explicit attention to the cost aspects of the various logistic planning issues in these models. The model described below illustrates this increased attention to cost.

5.2 A Logistic Support Cost Simulation Model for Aircraft Engines*

This model was designed primarily (1) to predict O&S costs of aircraft engines in terms of either manhours or dollars and (2) to serve as a tool for determining the sensitivity of O&S costs to various changes in an engine design or logistic support plan. It was developed initially by Detroit Diesel Allison, has been used for some time by Allison to predict O&S costs of Allison aircraft engines.

Inputs to the model include delivery schedules, failure rate distribution, labor cost estimates, and schedules of material costs and manhours per maintenance action. The model simulates operational, maintenance, and support resource environments. Maintenance activities addressed by the model include inspections, depot overhaul, depot and intermediate major repair, and intermediate minor repair, all of which

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* Further information with respect to use of this model is available from Mr Carlton Curry, Detroit Diesel Allison, Division of GM, or Mr Al Mikolanis, ASD/SMP-41, Wright-Patterson AFB, Ohio 45433 (phone 513/255-3187).

require engine removal. Forms of module maintenance addressed include depot overhaul, intermediate repair, and flight line repair both on and off the aircraft. * The output includes detailed forecasts of maintenance manpower and material costs for the various types of maintenance activities and maintenance actions.

The model has been used extensively by Allison with respect to the TF-41 and other aircraft engines and more recently, by the Air Force with respect to the TF-41 engine. The Allison model is conceptually similar but far from identified to many simulation models used by other turbine engine companies, aircraft manufacturers and others.

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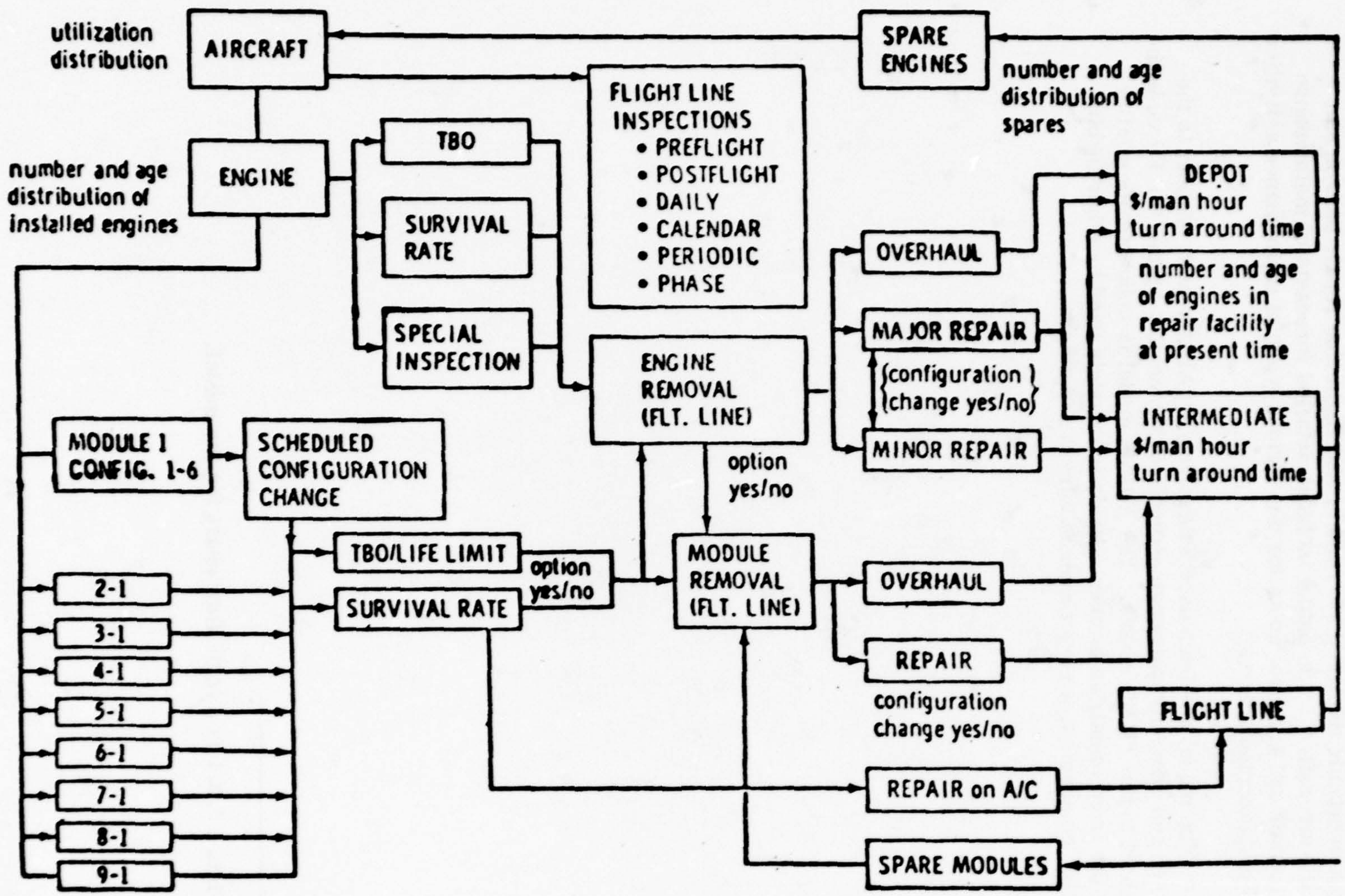
* Figure 5.2.1 is a logic flow chart for the model.

Figure 5.2.1

LOGISTIC SUPPORT COST MODEL – GENERAL LOGIC FLOW CHART



6. RELIABILITY IMPROVEMENT COST MODELS

6.1 Background

There is considerable evidence in the LCC literature indicating that more money spent to improve the reliability of present Air Force equipments could have resulted in far greater reductions in operating and support costs. The task of getting increased funding for reliability improvement work during the development cycle would be easier if development managers more clearly understood the relationship between equipment reliability and cost.

In recent years, several models have been developed for the purpose of explicitly identifying this relationship. Models of this kind can be very helpful in determining how much money should be budgeted to attain given levels of reliability and to determine the level of equipment reliability that minimizes life cycle costs.

The examples below represent two efforts to quantify the reliability-cost relationships.

6.2 A Model for Evaluating Weapon System Reliability, Availability and Costs*

The objective of this model is to reflect the relationships among system and subsystem reliability and availability design requirements and life cycle costs in order to provide a basis for making cost effective trade-off analyses to determine the optimum reliability and availability requirements for a system and its component subsystems. The model was constructed to determine the optimum reliability for each of any number of subsystems which comprise a specific system, such that the total life cycle cost of the system, as affected by reliability is a minimum. Three principle types of cost are considered:

(1) Cost of system downtime resulting from imperfect reliability. As reliability of a given subsystem decreases, downtime of the aircraft on which the subsystem is located tends to increase so that additional

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* "Criteria for Evaluating Weapon System Reliability, Availability, and Costs", Task 73-11, March 1974, Logistics Management Institute, 4701 Sangamore Road, Washington, DC 20016.

aircraft are needed to meet a given mission requirement. Downtime cost is defined in terms of the life cycle costs to buy these additional systems.

(2) Design, development, acquisition and program management costs associated with achieving given levels of reliability. A reliability growth model developed by J. T. Duane of the General Electric Company is used to reflect these costs.

(3) Maintenance and support costs associated with system, subsystem, and component reliability. The approach used here is to identify, from total maintenance costs reported or estimated, that portion which is recoverable, i.e., the cost that would not be expended if a failure did not occur. This recoverable cost therefore comprises the component of maintenance and support cost that varies with subsystem reliability.

The model was used in conducting case studies of the F-4C, F-105D, B-52H, and C-141A aircraft systems. The purpose of the studies was to evaluate the life cycle cost savings achievable if, at the time of system development, the optimum subsystem reliability had been determined and achieved through reliability growth programs. Input data for the model was gleaned from AFLC systems G033B, D056, D165A, K051, Project ABLE, and Project IROS. For each aircraft system, the model was exercised to determine the optimum MTBF for each major subsystem, the resultant MTBF for the entire system, and the total life cycle cost which would have been incurred if optimum MTBFs were achieved. The present MTBF experienced by each subsystem as found in the data was used to determine the life cycle cost under current MTBF conditions. The studies indicated in all four cases that there could have been significant reductions in life cycle cost if there had been additional investment in reliability growth during development. They also indicated that a return on this additional investment of 240 percent to 600 percent could have been realized.

The model was also used in an analysis of the AN/APQ-120 radar on the F-4E. The analysis sought to determine whether this low reliability radar should be improved via installation of higher reliability parts or replaced by a higher reliability radar, the WX-200. The study indicated that the former decision would result in a lower life cycle cost. This conclusion coincided with recommendations made by an Air Force/industry study that had been undertaken to determine a source of action with regard to this radar.

The examples above indicate that under appropriate conditions, the model can be used to produce relatively good estimates of optimum reliability levels. Efforts should be undertaken to prove the usefulness of this modeling approach in more Air Force reliability programs.

6.3 A Model for Trading Off System Reliability Performance and Cost*

The objective of this model is as follows:

Given several discrete options that vary in reliability performance (MTBF) and cost (acquisition cost or life cycle cost) for each of several subsystems of a weapon system, to find that set of subsystem MTBF options that maximizes system reliability performance (in terms of mission completion success probability (MCSP)) subject to a constraint on total cost of the system.

The model (known as the "Designing to System Performance/Cost" or "DSPC" model) was developed to be implemented with respect to a weapon system consisting of a set of mission critical subsystems. For each subsystem, estimates of parameters such as acquisition cost, MTBF, and average cost per repair are required as input data. The cost by which system performance is constrained in the model may be acquisition cost or total life cycle cost.

The optimization procedure is simple and easily implemented. It yields a concave curve reflecting MSCP as a function of cost and consisting of straight line segments that connect vertex points. The curve has the following properties:

(1) Each vertex represents the *maximum MCSP achievable at the* associated cost.

(2) No combination of subsystem options will yield a point above the curve.

(3) Moving along the curve from one vertex to an adjacent vertex is equivalent to changing only one subsystem option. Hence, intermediate points on this straight line segment can be realized (on a fleet basis) by equipping only a certain fraction of the fleet with the new option.

The model can be implemented with respect to existing systems when it is desired to determine an optimal allocation of funds for the reliability improvement of one or more of the system's subsystem.

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* Anderson, Richard H., et al, Models and Methodology for Life Cycle Cost and Test and Evaluation Analyses, OAS-TR-73-6, Section IV, Office of the Assistant for Study Support, DCS/Development Plans, Air Force Systems Command, Kirtland AFB, New Mexico 87117.

It was recently used in support of a Target Activated Munitions Program at Eglin AFB and the EF-111A and F-16 programs at Wright-Patterson AFB.*

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* Further information on these efforts is available from Mr Thomas E. Dixon, AFSC/XR/OAS, Kirtland AFB, New Mexico 87117. The F-16 application is treated in a thesis entitled, "Evaluation of F-16 Subsystems Options Through The Use of Mission Completion Success Probability and Designing to System Performance/Cost Models" by Capt A. Doman and Capt A. Dunkerley for the Air Force Institute of Technology Department of Systems Management (AFIT/ENS), Wright-Patterson AFB, Ohio 45433.

7. LEVEL OF REPAIR ANALYSIS MODELS*

7.1 Background

Another approach to reducing life cycle costs is the use of more effective and less costly maintenance or level of repair policies for Air Force weapons sytems. Several mathematical models have been developed in recent years for the purpose of determining the least cost level of repair policy for new equipments as they are introduced into the Air Force inventory. Most of these models fall into one of the three categories described below.

7.2 Single Item - Single Indenture Models**

This type of model simply adds up the various costs of each of three maintenance alternatives for a given line replaceable unit (LRU): (a) discard at failure, (b) repair at base, (c) repair at depot, and identifies the least cost of the three policies. This type of model has some limitations:

(1) It requires the use of an allocation procedure for costs of such items as support and test equipment that are used to repair more than one type of LRU. This usually results in a requirement for several iterations of the model for each LRU in order to ensure that LRUs designated for repair at a given location carry totally *allocated costs.*

(2) It does not explicitly cost out which of the three alternatives should be used at lower levels of repair, i.e., the shop replaceable unit (SRU) level, the module level, and the piece-part level. Instead, either an average or a maximum cost of the three alternatives at each of these lower levels is assumed to be known.

About 90 percent of all level of repair models currently in the literature fall into this category. Some of the more notable among these are:

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* Further information with respect to Level of Repair Analysis Models can be obtained from Mr Perry Stewart, AFALD/XRS, Wright-Patterson AFB, Ohio 45433 (513/255-5674).

** The term "indenture" refers to the level of hardware breakdown and disassembly, e.g., system, subsystem, line replaceable unit, shop replaceable unit, module, and piece-part.

(1) The Air Force Optimum Repair Level Analysis (ORLA) model as defined in AFLC/AFSC Manual 800-4. Various versions of this model have been used in several recent Air Force acquisition programs including the F-15 aircraft. In each of these cases, the model has been provided to the contractor as a minimum acceptable basis for determination of a repair level policy, and the contractor has been encouraged to extend and/or improve the model to more accurately reflect peculiar properties of the particular equipment being considered.

(2) The Navy Level of Repair Model as defined in Military Standard 1390.

(3) The McDonnell Douglas Level of Repair Model.

7.3 Single Item - Multi Indenture Models

Like the single item-single indenture model, this type of model costs out the discard at failure, repair at base, and repair at depot maintance alternatives for a given line replaceable unit. But unlike the single indenture type of model, it also explicitly costs out each of the three maintenance policies at the SRU, module, and piece-part level.

This type of model shares the first limitation described above, i.e., it requires several iterations when costs of support and test equipment used on several LRUs are involved. It usually uses an optimization procedure such as dynamic programming to cost out each maintenance alternative. Three models belonging to this category are the General Dynamics SG-8 Model, the Hughes Cost of Ownership Model (HCOM), and the Naval Air Development Center Level of Repair Analysis Model for Engines. The Navy model determines the optimum set of repair levels using exhaustive enumeration.

7.4 Systems Models

The systems approach costs out maintenance alternatives at the subsystem level, i.e., one level of indenture higher than the first two approaches. Hence, it is more comprehensive than these approaches in that it more accurately considers the optimum sequence of maintenance actions necessary to correct a failure and return the subsystem to serviceable condition. In addition, it avoids the problem of allocating costs of support equipment used on different LRUs of a given subsystem.

The primary limitation of the systems approach is its extensive requirement for input data. It also has the cost allocation problem in cases where support or test equipment is used on more than one subsystem.

A prime example of the systems approach is the Air Force Range Model (RGM). This model uses dynamic programming to calculate the combination of repair procedures for the total subsystem that will minimize support costs. To date, it has not been implemented in total on a major acquisition program, largely because of its extensive input data requirements.

8. MAINTENANCE MANPOWER PLANNING MODELS

8.1 Background

Maintenance manpower requirements clearly have a significant impact on the costs of maintaining most Air Force equipments. Mathematical models can be used as an aid in making two types of maintenance manpower decisions: (1) in evaluating the effects of alternative equipment designs on maintenance manpower requirements and (2) in evaluating the impact on cost of alternative maintenance policies. Careful use of these models can bring about substantial reductions in life cycle cost.

The model described below utilizes simulation to estimate maintenance manpower requirements. Simulation is a numerical technique for conducting experiments on a digital computer with a mathematical model that describes the behavior of a system over extended periods of time.

8.2 A Simulation Model for Estimating Maintenance Manpower Requirements*

The objective of this model is to provide an improved method for:

(1) Estimating the maintenance manpower requirements of a weapon system under development.

(2) Evaluating design tradeoffs for a weapon system under development on the basis of maintenance manpower requirements.

(3) Comparing alternative weapon systems being considered for acquisition on the basis of maintenance manpower requirements.

(4) Evaluating maintenance manning policies for weapon systems currently in the Air Force inventory.

The model simulates the function of flying a given set of aircraft, the function of maintaining this set of aircraft, and the interaction between these two functions. The functions are described to the model by

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* Further information about this model is available from Lt Col D. C. Tetmeyer, ASD/ENE, Wright-Patterson AFB, Ohio 45433 or Mr F. A. Maher, AFHRL/ASR, Wright-Patterson AFB, Ohio 45433 (513/255-3871).

parameters specified by the user. These inputs include:*

(1) Data that describe the weapon system, e.g., unit cost, failure rates of subsystems and components, types of AGE required by the system, etc.

(2) Data that describe the maintenance plan, i.e., class of maintenance (e.g., unscheduled, scheduled, or phase), type of maintenance (e.g., trouble-shoot), and resource requirements (e.g., maintenance crew size, task times, and required manning specialties and skill levels.

(3) Data that describe the mission, e.g., mission type, sortie length, priority, aircraft type, fleet size, lead times, delay times, launch times, and spares availability.

The aircraft operations and support requirements, and demands on aircraft imposed by the flight schedule interact with one another in the model. The model "flies" airplanes according to the mission schedule. As the schedule dictates, the model draws on the aircraft pool and processes appropriate numbers of aircraft (if available) through the presortie tasks (with the lead time for presortie processing determined by the user). Given that presortie tasks are completed in time to meet the mission schedule, the model "flies" the sortie. Concurrent with the accomplishment of the sortie, subsystem and component failure clocks are decremented (where these failure mechanisms are expressed in terms of "mean sorties between maintenance actions"). When the aircraft lands, it receives a basic postflight or turnaround postflight according to the operations schedule, and the model checks the clock values to determine if any failures have occurred. When unscheduled maintenance is performed, the model calls upon the various resource pools (manpower, spares, and AGE) to repair the malfunction. If the resources prescribed for this task are depleted or devoted to another task, the aircraft must wait (where, depending on the priorities assigned by the user, one task may preempt another and the resources directed to the higher priority task). After the failed equipment is repaired, the aircraft is returned to the pool and becomes available for flying again if called for by the mission schedule. Failed components that are removed from the aircraft during unscheduled maintenance are channeled into the

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* The model is divided into a series of modules, the main one of which is the LCOM (Logistics Composite) Model, originally developed by the RAND Corporation for AFLC.

shop where they may be repaired or processed for NRTS (not reparable this station) shipment to the depot. Either of these actions will eventually result in the return of the component to the spares pool.

The output format of the model reflects the interaction among support resources and their relationship to operational capability. It has two parts: (1) a Performance Summary Report which provides detailed information on the level of operation achieved during the simulation, and on the use and expenditure of resources necessary to sustain that level, and (2) a work center matrix which graphically depicts the number of personnel that must be available in a work center in order to meet "on aircraft" demands for maintenance over the span of time represented in the model. The model can be run repeatedly, each time with differing mission requirements. The set of differing manning requirements that result from these runs can then be input as data points to a regression program which calculates equations that reflect optimal work center manning for all appropriate points in the operations spectrum. These equations, in turn, serve as inputs to a Manpower Program which generates a manpower document (Basic Authorization) for any given flying hour program.

Since the model is modular in structure, portions of it can be used for other purposes. For example, the impact of different design alternatives on manpower can be determined using the Performance Summary Report. This tool may be helpful in determining optimal mixes of manpower, spares, and AGE resources.

The model has been successfully implemented in several Air Force programs so far and prospects for future use are good. It has been used:

(1) To estimate maintenance manning requirements during the prototype development phase of the A-X Program.

(2) To analyze the effects of design alternatives on maintenance manning in the A-10 Program.

(3) To compare the maintenance manning requirements of the A-10 and A-7 during the recent A-10 - A-7 flyoff.

The model is currently being used by TAC to evaluate maintenance manning policies for several aircraft currently in the inventory, and by the F-16 Program Office to evaluate the impact of aircraft design alternatives on maintenance manpower requirements. It is one of the central tools being used in the current effort to incorporate a life cycle cost estimating capability in DAIS (Digital Avionics Information System).

9. INVENTORY MANAGEMENT MODELS

9.1 Background

A significant reduction in the life cycle cost of a system can often be achieved by reducing the number of spare items required to keep the system operational. To a large extent, this can be achieved by better management of spares inventories.

During the past several years, a considerable number of mathematical models that treat various aspects of managing inventory systems have been developed. One of these models, called METRIC (Multi-Echelon-Technique-for-Recoverable-Item-Control), was specifically designed for the Air Force at the RAND Corporation. It is a method for determining optimal stock levels in a two-echelon, base and depot, inventory system for recoverable, i.e., reparable, items. Recoverable items are typically very expensive and their replacement demand rates are relatively low. However, it is important that they be managed properly since about 65 percent of the Air Force's total investment in spares is concentrated in these items.

The section below describes an extension of METRIC called MOD-METRIC. This model determines an optimal allocation of spare items for a system that can result in a considerable reduction in spares investment necessary to keep the system operational.

9.2 MOD-METRIC*

MOD-METRIC is an acronym for a mathematical model developed at Hq AFLC for the control of a multi-item, multi-echelon, multi-indenture inventory system for recoverable items, that is, items subject to repair when they fail. The objectives of the model are to describe the logistics relationship between an assembly and its subassemblies, and to compute spare stock levels for all echelons (e.g., base, intermediate, and depot

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* An article describing the MOD-METRIC technique, entitled "A Model for a Multi-Item, Multi-Echelon, Multi-Indenture Inventory System" by Major John A. Muckstadt, Hq AFLC, Wright-Patterson AFB, Ohio 45433 can be found in Management Science, Volume 20, No. 4, December 1973, Part I.

level shops) for the assembly and subassemblies with explicit consideration of this logistics relationship.* In particular, the model is used to determine spare stock levels at each echelon which minimize total expected base backorders for the assembly subject to a constraint on investment in spares. By changing the level of this constraint and solving the model repeatedly, a curve of minimum expected base backorders achievable versus dollars spent on spares can be derived for use in determining an appropriate level of investment for spares.

Required inputs to MOD-METRIC include frequency of removals of each subassembly, average resupply times, not reparable this station (NRTS) rates, average repair time at each echelon, etc. In other words, a well defined maintenance concept is required by the model so that its usefulness for conceptual phase analysis is limited. However, the model can be used effectively once design options are defined, to determine the impact of alternative maintenance concepts on spares requirements.

MOD-METRIC has been used by the Air Force as a method for computing spare stock levels for the F-15, and is currently being used on the F-16 program. The B-1 Program Office has also used it. An AFLC pamphlet, AFLCP 57-13, has been prepared to provide detailed instruction on using the AFLC CREATE system to access and use MOD-METRIC computer programs. These instructions may be used by personnel who perform analysis of resource allocation or are authorized to use MOD-METRIC to compute requirements.

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* The logistics relationship is described in the model by an equation. This equation reflects the average resupply time of the assembly as a function of (1) the probabilities that a given assembly failure was isolated to each of the components comprising the assembly and (2) the average resupply time for each of these components.

10. WARRANTY MODELS

10.1 Background

In recent months, the Air Force has been seriously examining the pros and cons of a more widespread use of reliability improvement warranties (RIW) in the acquisition of new weapons systems/equipments. Recent studies have concluded that a properly constituted and applied warranty can yield significant reliability and LCC benefits. The Director, Procurement Policy, Hq USAF, has recently published a set of interim general guidelines with respect to RIW application criteria, funding of RIWs, essential elements to be included in an RIW contract clause, determination of the cost-effectiveness of an RIW provision, and evaluation approaches for assessing the cost-effectiveness of an RIW after it has been implemented. It should be noted, however, that these guidelines provide no specific cost methodology to be used in determining cost-effectiveness. In order to bridge this gap, the Government must develop models that will compute parameters for aiding in making warranty-related decisions, e.g., optimal warranty time period, break-even costs, etc. One such model is described on the following pages.

10.2 An LCC Model for Use in Negotiating Reliability Improvement Warranties*

The objective of this model is to evaluate the life cycle costs associated with a reliability improvement warranty (RIW) provision in the procurement of defense avionic equipment. The model computes:

(1) Savings achievable by using a warranty as a function of length of warranty period in order to determine an optimum warranty period length.

(2) The break-even or "indifference" price for items purchased under a warranty provision as a function of length of warranty period,

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* Use of Warranties for Defense Avionic Procurement, ARINC Research Corporation, sponsored by Defense Advanced Research Projects Agency, ARPA Order No. 2360, also Final Technical Report No. RADC-TR-73-249, June 1973. The monitors for this contract were Mr Russell Shorey, ODDR&E, The Pentagon, Washington, DC 20330, and Mr A. Feduccia, RADC/RBRS, Griffiss AFB, New York 13440.

i.e., that price whereby the expected total user cost under warranty is equal to the total cost that the user would expect to incur without a warranty.

The model is developed to be applicable during the development and preproduction stages when consideration of a warranty provision for the production contract is most important. It considers three cost elements for any given equipment procurement: initial acquisition costs, direct costs associated with failures, and indirect costs associated with maintenance support. In simplified form, the model can be stated as follows:

> Life Cycle Cost over (O, T) = Number of units purchased x purchase price per unit + expected number of failures over (O, T) x cost per failure + maintenance support costs over (O, T).

The detailed form of the equation above depends on whether it is being formulated to reflect a warranty or a no-warranty situation. Except for direct reliability modification cost, the model assumes that the user incurs the same kinds of costs in the warranty case as in the no-warranty case. Clearly, his in-house direct maintenance costs will be less in the warranty case. His initial support costs will also be less, especially if his equipment is new to the inventory. However, there will be additional costs for warranty administration. The model assumes that all costs expected to be incurred by the contractor in the warranty case are included in the contract price, burdened by fee and risk factors.

To date, the RIW LCC model has not been used in a real world procurement because (1) it is very complex and hence, difficult to understand, and (2) several of its assumptions regarding failure rates, effectiveness of modifications, etc., have not been sufficiently validated.

In late spring of 1974, a follow-on contract with the objective of making the model workable and useful as a decision tool was awarded.* Some of the contract's specific goals are:

(1) To determine if the objectives of the model in the way it

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* The monitor for this contract is Mr Gene Fiorentino, RADC/RBRS, Griffiss AFB, New York 13440. A report on the research done under this contract should be available in mid-1976.

computes LCC in the no-warranty case are consistent with the objectives of the more traditional models that have been used to estimate LCC in recent procurements.

(2) To more fully develop the concept of reliability growth during the warranty period in the model.

(3) To implement the model on an experimental basis in some future procurements, e.g., the ARN-XXX TACAN currently in development.

(4) To determine the sensitivity of the model to labor rates and to examine the model's assumptions about labor rates.

(5) To test the validity of the probability distribution used by the model to reflect the frequency of equipment modifications.

Hopefully, this study will provide solutions to many of the problems that now plague warranty models, so that models of this kind will soon be an effective aid when deciding whether or not a warranty should be used, how much it should cost, and what is the best warranty period length.

BIBLIOGRAPHY

1. "Aircraft Avionics Tradeoff Study, Volume II: Concept Development and Tradeoff, Part II, Equipment Tradeoffs", J.R. Coult, et al, Honeywell, Inc., USAF Tech Report ASD/XR 73-18, September 1973.

2. "Aircraft Avionics Tradeoff Study, Volume III: Concept Application, Evaluation, and Implementation", R.K. Crowe, et al, Honeywell, Inc., USAF Tech Report ASD/XR 73-18, September 1973.

3. "Application of the A-X 10 Year Operating and Support Cost Model to the F-4E", Operations Analysis Memo No. 14, R.E. Cavender, Operations Analysis Office, Hq AFLC, Wright-Patterson AFB, Ohio 45433, March 1971.

4. "Avionics Life Cycle Cost Model", Aircraft Avionics Tradeoff Study, R.N. Furtaw, et al, Hughes Aircraft Company, Canoga Park, California 91304 under Air Force Contract F33615-73-C-4137 to Deputy for Development Planning, ASD/XR, Wright-Patterson AFB, Ohio 45433, Report ASD/XR 73-19, November 1973.

5. "CO-AMP: Cost Optimization and Analysis of Maintenance Policies", RCA, Camden, New Jersey 08102.

6. "Computerized Model for Life Cycle Cost Analysis", Lear Siegler Publication No. GRR-006-0474, Lear Siegler, Inc., Instrument Division, 4141 Eastern Avenue S.E., Grand Rapids, Michigan 49508, 1 April 1974.

7. "Cost Analysis of Avionics Equipment", Air Force Avionics Lab (AFAL) Technical Report 73-441, February 1974.

8. "Criteria for Evaluating Weapon System Reliability, Availability, and Costs", Task 73-11, Logistics Management Institute, 4701 Sangamore Road, Washington, DC 20016, March 1974.

9. "LCC-1: Life Cycle Costing Procurement Guide (Interim)", Department of Defense, Washington, DC 20330, July 1970.

10. "LCC-2: Casebook - Life Cycle Costing in Equipment Procurement", Department of Defense, Washington, DC 20330, July 1970.

11. "LCC-3: Life Cycle Costing for System Acquisition (Interim)", Department of Defense, Washington, DC 20330, 13 September 1972.

12. "Life Cycle Cost Comparisons of Avionic System Design Alternatives", P.S. Kilpatrick and A.L. Jones, Proceedings of the IEEE 1974 National Aerospace and Electronics Conference NAECON '74, 13-15 May 1974, pp 514-520.

13. "Life Cycle Cost Design Trade-Offs for a Developmental UHF Modular Transceiver", Norbert Schroeder and Carl Sonty, Tracor Sciences and Systems, Tracor, Inc., 1117 North 19th Street, Suite 1200, Arlington, Virginia 22209.

14. "A Life Cycle Cost Model for Inertial Navigation Systems", Thomas D. Meitzler and Russell M. Genet, Plans and Programs Office, Aerospace Guidance and Metrology Center (AGMC), Newark Air Force Station, Newark, Ohio 43055, 13 June 1974.

15. "Life Cycle Cost of Modular Electronic Equipment", TD 1980, November 1973, Revision 1, 8 February 1974, Naval Avionics Facility, Indianapolis, Indiana 45218. Distribution limited to U.S. Government Agencies only.

16. "Logistics Support Cost (LSC) Model User's Handbook", AFLC/AQMLA, Wright-Patterson AFB, Ohio 45433, January 1976.

17. "A Model for a Multi-Item, Multi-Echelon, Multi-Indenture Inventory System", John A. Muckstadt, Management Science, Volume 20, No. 4, Part I, December 1973.

18. "Model for Life Cycle Cost Analysis", William J. Bonner, Litton Systems, 5500 Canoga Avenue, Woodland Hills, California 91364.

19. "Models and Methodology for Life Cycle Cost and Test and Evaluation Analyses", OAS-TR-73-6, Richard H. Anderson, et al, Office of the Assistant for Study Support, DCS/Development Plans, Air Force Systems Command, Kirtland AFB, New Mexico 87117.

20. "Operating and Support Cost Comparison A-7 Versus A-10", Major F. Swafford, DOD/ODDPA&E, The Pentagon, Washington, DC 20330, 2 May 1973.

21. "Optimum Repair-Level Analysis (ORLA) (AFLCM/AFSCM 800-4)", Hq Air Force Logistics Command, Wright-Patterson AFB, Ohio 45433, Hq Air Force Systems Command, Andrews AFB, Washington, DC 20331, 25 June 1971.

22. "Programmed Technique for Evaluating Cost Trade-Offs (PROTECT)", K.J. Gibson, A158-D-E Rev 2173, Autonetics Division, Rockwell International, 3370 Miraloma Avenue, Anaheim, California 92803.

23. "Radar Reliability and Its Impact on Life Cycle Costs for the APQ-113, -114, -120 and -144 Radars", ASD-TR-73-22, Research Study of the General Electric Company, Utica, New York 13503. Under contract to Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson AFB, Ohio 45433, April 1973.

24. "Recoverable Inventory Control Using MOD-METRIC", (AFLCP 57-13), Hq Air Force Logistics Command, Wright-Patterson AFB, Ohio 45433, 28 September 1973.

25. "The REDUCE Model: Description", ASD/XR 72-34, James R. Cerone, et al, Caywood-Schiller Division, A.T. Kearney, Inc. Under contract to Deputy for Development Planning, ASD/XR, Wright-Patterson AFB, Ohio 45433, July 1972.

26. "RGM1 - Executive Summary", Operations Analysis Report No. 9, Jay F. Williams, Operations Analysis Office, Hq Air Force Logistics Command, Wright-Patterson AFB, Ohio 45433.

27. "Reliability Acquisition Cost Study", Salvatore P. Mercurio and Clyde W. Skaggs, General Electric Company, Contract F30602-72-C-0226, Project 5519, Job Order No. 55190256, RADC/RBRS, Griffiss AFB, New York 13441.

28. "Reliability Growth in Real Life", Ernest O. Codier, General Electric Company, Utica, New York 13503, 1968 Annual Symposium on Reliability, pp 458-469, January 1968.

29. "Review of the Application of Life Cycle Costing to the ARC-XXX/ARC-164 Program", Avionics Program Office, Aeronautical Systems Division, Wright-Patterson AFB, Ohio 45433, August 1974.

30. "Review of the Application of Life Cycle Costing to the A-X/A-10 Program (1970-1973)", Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost, ASD/ACL, Wright-Patterson AFB, Ohio 45433, October 1973.

31. "Summary of Proceedings: Life Cycle Cost Methods Workshop", 31 October - 1 November 1973, AFSC/AFLC Joint Commanders' Working Group on Life Cycle Cost, (ASD/ACL), Wright-Patterson AFB, Ohio 45433.

32. "Use of Warranties for Defense Avionics Procurement", H. Balahan, and B. Retterer, ARINC Research Corporation, sponsored by Defense Advanced Research Projects Agency, ARPA Order No. 2360, also Final Technical Report No. RADC-TR-73-249, June 1973.

33. "Using Logistics Models in System Design and Early Support Planning", R-550-PR, R.B. Paulson, et al, The RAND Corporation, Santa Monica, California 90406, February 1971.

34. "Cost Estimating Relationships for Predicting Life Cycle Costs of Inertial Measurement Unit Maintenance" (SLSR 16-75A), a thesis in the AFIT School of Systems and Logistics by Lt Lynn M. Lynch and Capt Neil V. Raymond, January 1975 (DDC #ADA006344).

35. "Study of Reliability Prediction Techniques for Conceptual Phases of Development", RADC-TR-74-235, Hughes Aircraft Company for RADC (RBRS), Griffiss AFB, New York 13441, October 1974.

36. Relating Technology to Acquisition Costs: Aircraft Turbine Engines (R-1288-PR) by J.R. Nelson and F.S. Timson, The RAND Corporation, Santa Monica, California 90406, March 1974.

37. "Understanding and Evaluating Life Cycle Cost Models", J.D.S. Gibson, ASD/ACL, October 1975.

38. "An Adaptation of the AFLC Logistic Support Cost Model for Aircraft Simulators", AFLC/AQA, January 1976.

39. "Reliability Growth Study", RADC-TR-75-253, Hughes Aircraft Company for RADC, October 1975.

40. "Reliability Acquisition Cost Study (II)", RADC-TR-75-270, Hughes Aircraft Company for RADC, November 1975.

41. "A Summary and Analysis of Selected Life Cycle Costing Techniques and Models", AFIT Thesis, L. Doner and Capt B. Oswald, August 1974.

42. "Simulating Maintenance Manning for New Weapon Systems: Building and Operating a Simulation Model", Air Force Human Resources Laboratory, Brooks AFB, Texas, December 1974.

This document is one of a series prepared to assist Air Force personnel understand and apply life cycle costing techniques. Other documents in this series include:

Life Cycle Cost Plan Preparation Guidance, October 1975.

Understanding and Evaluating Life Cycle Cost Models, October 1975.

Life Cycle Cost Analysis Guide, November 1975.

Supplemental Life Cycle Costing Program Management Guidance, January 1976.

Life Cycle Cost Procurement Guide, August 1976.

Copies of all of these documents are available from ASD/ACL, WPAFB, Ohio 45433.